MEASURING TECHNICAL EFFICIENCY AND TECHNOLOGICAL GAPS OF BEEF FARMERS IN THREE REGIONS OF BOTSWANA: AN APPLICATION OF META-FRONTIER APPROACH

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Abstract

Differences in resource endowment between regions influence the technologies used in livestock production and cause location-specific effects on production and technical change. Access to technologies may differ within regions due to different farm characteristics. Against this background, the study applied a stochastic meta- frontier model followed by a Tobit regression to estimate technical efficiency and meta-technology ratios and assess factors influencing efficiency of beef farms across three regions in Botswana. Results show that the average technical efficiency level is 0.496 for the whole sample and 0.194, 0.331 and 0.318 for beef farms in South East, Central and Chobe regions, respectively. Considerable scope is identified for improving beef production in Botswana, and targeting is enabled by the differential results across the farm types. Policy analysis using models that assume different beef farm types operate under similar technology present a misleading picture. Considering the importance of livestock sector in poverty reduction, there is a need for appropriate and targeted policies directed towards enhancing efficiency. Especially, such policies should be targeted on provision of technology-related services such as controlled breeding methods.

Keywords: Beef production; meta-frontier, technical efficiency determinants; Botswana

1. Introduction

The measurement of technical efficiency (TE) assesses the performance of firms' use of resources to produce goods and services (Pascoe, et al, 2003). Further, it can provide useful information for potential efficiency gains and enhanced competitiveness, at existing levels of resources and technologies (Abdulai and Tietje, 2007). Apart from, investigating factors that influence TE, the analysis offers vibrant understanding of key variables that might be worthy of attention in policy making to ensure optimal resource utilization and allocation which in turn have implication for productivity and livelihood improvement. Technical efficiency analysis has been applied extensively in arable, dairy and integrated farming with limited focus on livestock in general and beef in particular (Otieno et al, 2014).

Building on previous work in Botswana, the present study investigates technical efficiency of beef with the main focus on regionally categorized traditional or smallholder beef farms. According to Statistics Botswana (2013), smallholder beef farmers own 88 and 98 percent of the nation's cattle and small stock herd, respectively, and they mainly operate under communal or open access rangelands. The current study investigates determinants of TE in three beef cattle production regions in Botswana. Differences in resource endowment among regions are expected to influence the adoption of technology and the variation of TE. The smallholder beef farms are accordingly categorized by region, namely South

East, Central and Chobe. The main objective behind such classification is to examine the impact of the apparent differences in technology and organizational structure, as well as asset ownership and human capital both within and between these regions, on technology gaps and technical efficiency. It is hypothesized that there is significant technological gap differences, and hence factors that affect TE. These differences in technological gap emanate from the apparent differences on environmental conditions, climatic constraints and resource endowment which impact the farmer's ability to access and utilize of agricultural inputs.

Investigation of the determinants of TE in beef cattle production should provide analytical insights to enhance beef supply for domestic and export markets (EU markets). Botswana is currently does not fully utilize its preferential access to EU markets (Hachigonta et al, 2013). The current study employs a two-step approach using stochastic meta-frontier-Tobit method to estimate TE and subsequently investigate determinants of the TE across Botswana's different regions. This idea has been inlayed into a meta-frontier function to allow measuring TE for each group of producers under group-specific production frontiers (Hayami and Ruttan 1970; Battese and Rao 2002). The stochastic meta-frontier-Tobit method involves, first, estimating TE through a meta-frontier approach as suggested by Battese and Rao (2002), and subsequently using a Tobit model (Tobin, 1958) to investigate determinants of the TE. The stochastic meta-frontier-Tobit method is preferred to using a one-step stochastic frontier approach (SFA) because it accounts for technology gaps and allows comparison of TEs across heterogeneous groups (Battese and Rao, 2002; Villano et al., 2010), such as regional productivity.

The remaining part of the paper is organized as follows: section 2 provides the analytical framework; section 3 explains the study area, data used and empirical estimation followed in the study; section 4 discusses the results, and section 5 offers key conclusions from the results and their policy implications.

2. Analytical framework

As noted above, the estimation procedure involves, first, applying SFA to investigate TEs across the different regions. As the SFA allows only comparison of farms operating with similar technologies, its use entails an assumption of similar technologies across farms which actually differ: this can result in erroneous measurement of efficiency by mixing technological differences with technology-specific inefficiency (Tsionas, 2002). The next step involves estimation of a meta-frontier, an approach recently proposed by Battese and Rao (2002), to adjust the TE scores from SFA in order to account any differences in technology. Finally, a Tobit model is used to assess variations in the TE scores obtained from the meta-frontier estimation.

Suppose that there are j groups or regions in the cattle industry. The stochastic production frontier is specified as:

$$Q_i = f(x, \beta)\exp(v - u) \quad (1)$$

Where Qi is the output of the i^{th} farm

X is the vector of inputs used by the i^{th} farm

β is a vector of production input parameters to be estimated

v is assumed to be independent and identically distributed random error, representing the effects of statistical noise, having a normal distribution with zero mean and variance given by σ^{2}, i.e. $v \sim \mathrm{N}(0, \sigma_v^2)$.

u represents the farm-specific technical inefficiency in production and is assumed to be independent of *v* and non-negative truncation of the half-normal distribution, i.e. $u \sim |\mathrm{N}(0, \sigma_u^2)|$ (Battesse and Coelli, 1995) and it follows that (Aigner *et al*., 1977):

$$\sigma^2 = \sigma_v^2 + \sigma_u^2 \quad (2)$$

When data are in logarithm terms, u is a measure of the percentage by which a particular observation or farm fails to achieve the frontier, ideal production rate (Greene, 2003).

Following Battese and Corra (1977), the departure of output from the frontier due to technical inefficiency is defined by a parameter (γ) given by:

$$\gamma = \frac{\sigma_u^2}{\sigma^2}\text{, such that } 0 < \gamma < 1 \quad (3)$$

Suppose that u=Mδ where M is a vector of the various factors that influence the technical inefficiency of farms, while δ is a vector of inefficiency parameters to be estimated. Thus, the stochastic frontier production function (equation 1) for j region can be re written as (Battese and Rao, 2002):

$$Q_{ij} = f\left(X_{ij}, \beta_j\right) \exp(v_{ij} - M_{ij}\delta) \quad (4)$$

where Q_{ij} is the output for the i^{th} farm in the j^{th} region; f(.) is the functional form used; β_j is a vector of input parameters to be estimated for the j^{th} region;

M is a vector of factors that influence the technical inefficiency of farms; and δ is a vector of inefficiency parameters to be estimated.

Assuming that any deviation is pure statistical noise (such as measurement errors and other unobserved factors or those outside a farmer's control e.g., animal disease outbreak and weather), the TE can be expressed as the ratio of actual output observed to that expected maximum level from the use of available inputs (Boshrabadi et al., 2008):

$$TE_{ij} = \frac{f\left(X_{ij}, \beta_j\right) \exp(v_{ij} - M_{ij}\delta)}{f\left(X_{ij}, \beta_j\right) \exp\,(v_{ij})} = -M_{ij}\delta \quad (5)$$

Any frontier measures individual farmers' performance, relative to the dominant technology in a particular region. As noted above, all farms do not necessarily operate using the same technology and assuming similar technology might result in measurement errors.

Therefore, the model in (5) is inappropriate for comparing the performance of farms across different groups of farms that are not technologically identical (O'Donnell et al., 2008). To measure efficiency and technology gaps of firms producing in different technological environments, Battese and Rao (2002) and Battese et al. (2004) proposed the use of a meta- frontier production function which is considered to be a smooth function that envelops the explained (deterministic) components of the group stochastic frontier functions (e.g., for different regions). It explains deviations between observed outputs and the maximum possible explained output levels, in the group frontiers.

The meta-frontier equation can be expressed as:

$$Q^* = f(X_i, \beta^*) \text{ i=1, 2 ….N} \quad (6)$$

where f (.) is a specified functional form; Q* is the meta-frontier output; and β* denotes the vector of meta-frontier parameters satisfying the following constraints:

$$f(X_i, \beta^*) > \; f(X_i, \beta_j) \text{ for all j = 1, 2…j} \quad (7)$$

In order to satisfy the condition in (7), an optimization problem is solved where the sum of absolute deviations (or squared deviations) of the meta-frontier values from the values of the group frontiers are minimized as:

$$\min \textstyle\sum_{i=1}^{n} |\, ln\; f(X_i, \beta^*) - \ln f\left(X_i, \beta_j\right)| \quad (8)$$

$$s.t. f(X_i, \beta^*) \geq \ln f\left(X_i, \beta_j\right)$$

The standard errors of the estimated meta-frontier parameters can be obtained through bootstrapping or simulation methods.

In terms of the meta-frontier, the observed output for the i^{th} farm in the j^{th} region (measured by the stochastic frontier in equation 4) can be expressed as:

$$Q_{ij}^* = \exp\left(-M_{ij}\delta\,\right).\frac{f\left(X_i\,, \beta_j\right)}{f\left(X_i\,, \beta^*\right)}\;. f(X_i, \beta^*) \exp\,(v_{ij}) \quad (9)$$

where (recall from (5) that, $-M_{ij}\delta = TE_{ij}$) the middle term in (9) represents the technology gap ratio (TGR) that can be expressed:

$$TGR_i = \frac{f(X_i, \beta_j)}{f(X_i, \beta^*)} \tag{10}$$

Given the observed inputs, according to Battese and Rao (2002), the TGR measures the ratio of the output for the frontier production function for the *jth* group or region relative to the potential output defined by the meta-frontier. TGR values approaching 1 imply that a farm in a given region is producing nearer to the maximum potential output given the technology available for the whole beef industry.

To account for the wider environment in which production takes place and other factors that might influence the potential productivity gains from a given technology, the TGR is, hereafter, referred to as meta-technology ratio (MTR).

The TE of the i^{th} farmer relative to the meta-frontier (TE_i^*) is the ratio of the observed output for the i^{th} farm relative to the meta-frontier output, adjusted for the corresponding random error such that:

$$TE_i^* = \frac{Q_{ij}}{f(X_i, \beta^*)\exp(v_{ij})} \tag{11}$$

Following (5), (9), and (10) TE_i^* can be expressed as the product of the TE relative to the stochastic frontier of a given region and the MTR:

$$TE_i^* = TE_{ij}.MTR_i \tag{12}$$

Finally, the determinants of technical efficiency are investigated using a two-limit Tobit (Wooldridge, 2002), specified as:

$$\theta^{k*} = M\delta + e$$

$$\theta^{k*} = \{(0\ if\ \theta^{k*} < 0); (\theta^{k*}\ if\ 0 < \theta^{k*} < 1); (1\ if\ \theta^{k*} > 1)\} \tag{13}$$

where θ^{j*} and θ^{j} are the latent and observed values of the meta-frontier TE scores, respectively; M denotes the vector of socio-demographic and other independent variables assumed to influence efficiency; and e is the random term.

3. Data and estimation

3.1. Description of the study area

This paper uses farm-level cross sectional survey data collected in 2013 under the auspices of a development research project[1]. A multi-stage cluster (area) sampling approach (Horppila and Peltonen, 1992) was used to select a sample from the population. First, the central district (Botswana's largest district), was divided into four sub districts (Serowe, Letlhakane, Selebi-Phikwe and Nata), to account the differences in farming system, ecology and soil type, to form six clusters. Then within a cluster, extension areas[2] were randomly selected from lists of all extension areas, taking into account the general distribution of cattle in the study area. Subsequent stages involved a random selection of crushes[3] or sample of locations, from which a number of farmers were randomly selected.

The project assembled detailed information on costs of and returns to livestock production, along with selected technical, physical and demographic variables for farm household operations. Coverage of the survey was restricted to 600 primarily livestock farmers in these three major livestock production districts of Botswana, (South East, Chobe and Central districts of Botswana).

[1] The *Smallholder Livestock Competitiveness* Project is funded by the Australian Centre for International Agricultural Research (ACIAR) and implemented by the International Livestock Research Institute (ILRI) in partnership with the Botswana Ministry of Agriculture's Department of Agricultural Research (DAR).
[2] Extension areas are areas with in districts that are classified based on delivery of agricultural extension services.
[3] Normally the veterinary district offices keep list of farmers by crushes. Thus, list of farmers was provided by crushes for each extension area in respective district/sub district.

According to statistics Botswana (2014), the South East administrative region is adjacent to Gaborone, the capital of Botswana and the district headquarters (Ramotswa) is about 40 kilometres from the capital city, Gaborone. The agricultural district is known as Bamelete/Tlokweng and is one of the five districts forming the Gaborone Agricultural Region.

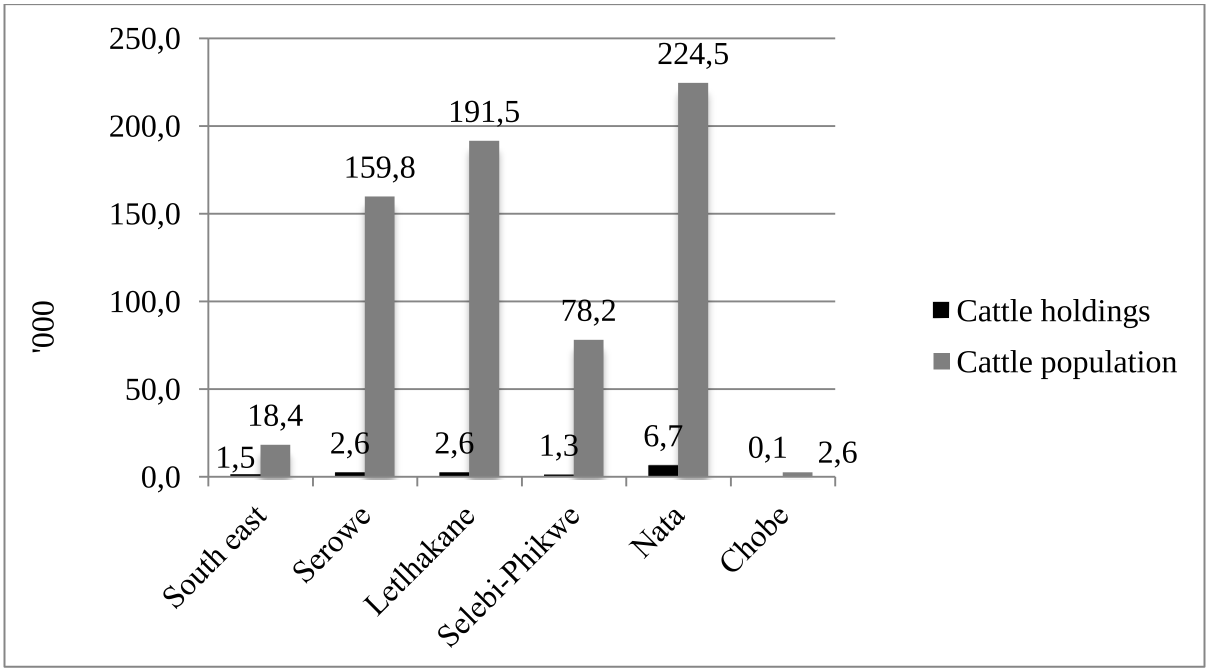

Figure 1: Cattle holdings and population in the study area during the year 2012 (Source: Statistics Botswana, 2014)

The district held 18,378 cattle which represented 0.81 percent of the Botswana's total cattle herd, while the cattle holdings represented 2 percent of the total cattle holdings (Figure 1 and Figure 2). The Chobe district lies on the north western part of Botswana and is known for its tourism because of abundance of rich wildlife resources. The Chobe district, a predominately tourist area with rich wildlife resources, forms what is known as the Maun Agricultural Region together with Ngamiland east and Ngamiland west. According Figure 2, in 2012, the proportion of cattle held in the district was 0.12 percent. The reasons for this low proportion of cattle in Chobe area are: First the large national parks and forest conservation in the area limits the amount of land available for livestock rearing in terms of grazing land. Second, the area is infested by Tsetse fly which causes nagana in cattle and hence historically has not been widely populated by cattle. Third and last, the area is the home to buffaloes who are carriers of the FMD virus and hence not suitable for rearing cloven hoofed animals. The area is considered as red zone or FMD area by world organization of animal health (OIE) and Department of veterinary services. Farmers in the area are not allowed to trade to other regions and Botswana meat commission without 21 days quarantine, which creates extra cost for farmers. The ILRI/ACIAR/MOA project included this area as part of the survey to explore the differences in competitiveness of farmers in FMD and non FMD areas.

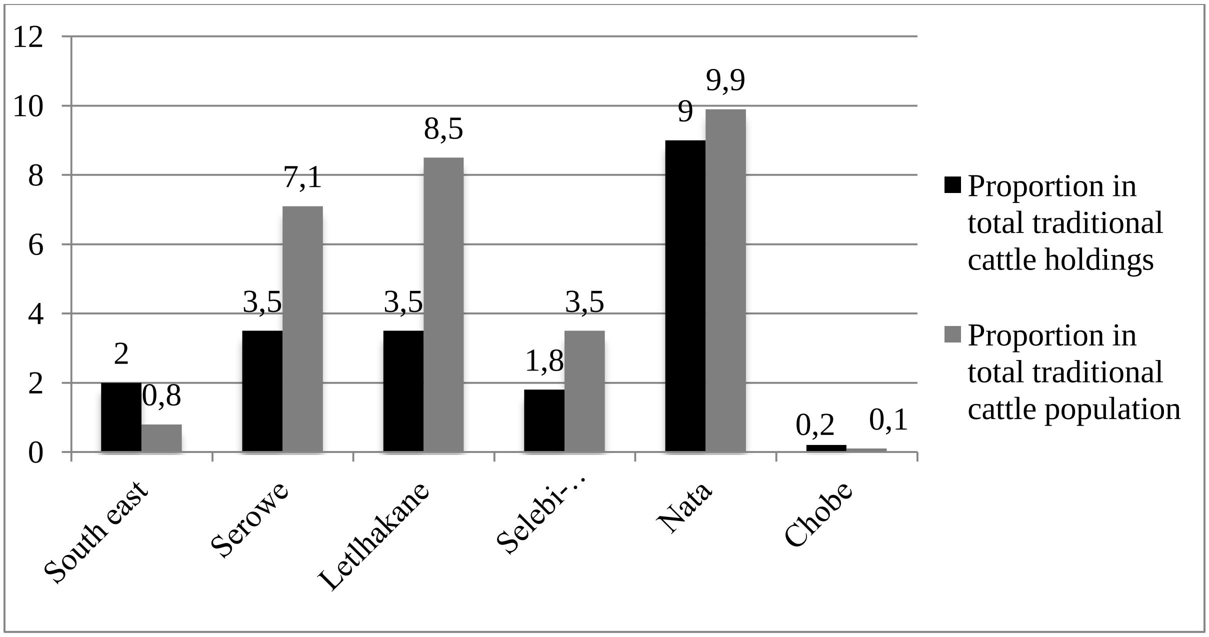

Figure 2: Proportion of traditional cattle holdings and population of the study area during the year 2012 (Source: Statistics Botswana, 2014)

The Central Agricultural Region is the largest geographical agricultural region in Botswana and consists of seven agricultural districts. The data for the study was collected from three districts in the agricultural region; Serowe, Selebi-Phikwe, Letlhakane and Nata in Central Administrative District, but falling under Tutume Agricultural Region. The Central Agricultural Region had a total of 654,058[4] cattle population of which 78,181 were in Selibe-Phikwe, 159,800 in Serowe, 191,535 in Letlhakane and 224,542 in Nata (Figure 1). The agricultural district as a whole kept 28.94 percent of the national cattle herd in the traditional sector (Figure 2). The reason for this is that the region has vast tracks of land suitable for cattle farming, despite some part of the region, around Nata and Selebi-Phikwe, is prone to foot and mouth diseases (FMD) and categorized as FMD zone.

For the purposes of the present study, beef farmers are grouped by according regions. Such analysis at the regional level of beef production is proposed as desirable because it is likely that these farms are operating with different technologies which could emanate from the environmental condition of specific region. It is also expected that differences in technology and organizational structure, as well as asset ownership and human capital both within the beef farms and between these regions could cause or underlie significant differences in the technologies used by the farms. From the policy point of view, it is of interest for the study to distinguish the regional differences in in their mean efficiency levels, technology gaps and identify common determinants of technical efficiency. These assertions require statistical testing, as there would be no good reason for estimating the efficiency levels of beef production in different regions relative to a meta-frontier production function if these farmers are found out to operate under the same technology (Battese et al, 2004). A likelihood-ratio (LR)[5] test of the null hypothesis, that the beef farm stochastic frontier models are the same for all farms in Botswana, was calculated after estimating the stochastic frontier by pooling the data from all beef farms. The value of the

[4] This figure includes the population of cattle in Nata, which falls under Tutume Agricultural Region.
[5] Following Battese et al (2004), the likelihood ratio (LR) statistic calculated as : -2{ln[L(Ho)]- ln[L(H1)]} where ln[L(Ho) is the values of the log likelihood function for the stochastic frontier estimated by pooling the data for all beef farms and ln[L(H1)] is the sum of the values of the log likelihood functions for the three regional beef production frontiers. The degrees of freedom for the Chi-square distribution involved are 34, the difference between the number of parameters estimated under H_1 and H_0.

LR statistics, 78.1, is highly significant (Kodde and Palm, 1986). (See appendix 1 for further explanation the variables used in the model)

3.2 Descriptive statistics

Selected farm characteristics from the survey, subdivided by the districts or regions, are shown in Table 1. About 39%, 35% and 26% of the beef farm households in the survey, used for this study, are from South east, central and Chobe regions, respectively.

On average, beef farms in Central district have larger herd size, 36.26 beef equivalent, than farms in the South East and Chobe districts.

The later tend to keep more indigenous (local) cattle breeds (75% and 83% for South east and Chobe, respectively) such as Tswana, which are relatively more adapted to hot and dry conditions. In contrast, the mixed farm types have a majority of crossbred and pure exotic breeds.

Table 1: Descriptive statistics of sample characteristics

	South East (N=219)	Central (N=200)	Chobe (N=149)	Pooled sample (N=568)
% of farmers	39	35	26	100
Herd size	13.17[c]	36.26[a]	21.63[b]	23.5
Main cattle breed is indigenous (% of farmers)	75[b]	55[c]	83[a]	69.9
Dependence on non-farm income (% of farmers)	58[a]	47[b]	51[b]	51.9
Education of Household head (years)	3.46[b]	5.93[a]	5.44[a]	4.85
Farms with income from other agricultural sales (% of farmers)	48[b]	59[a]	56[a]	54.22
Crop land area (Ha)	2.53[b]	7.64[a]	6.17[a]	5.29
Distance to commonly used market (Kms)	35.64[c]	55.26[b]	68.40[a]	51.1
Average age of household head (years)	59.75[a]	55.26[b]	59.91[a]	58.2
Experience in cattle production (years)	22.3[c]	24.6[b]	26.7[a]	24.3
Gender (% of female farmers)	21[a]	24[a]	19[a]	21.7
Membership in agricultural groups	15[b]	15[b]	20[a]	16.0
Access to prior market information in the past year (% of farmers)	66[a]	62[b]	57[b]	61.9
Access to veterinary services (% of farmers)	86.7[a]	78.5[b]	74.4[b]	80.63

Use of controlled cattle breeding method (% of farmers)	9[b]	20[a]	7[c]	12.6
More than 50% cattle sales to BMC (% of farmers)	5[b]	22[a]	5[b]	10.7

Note: [a,b,c] differences in the superscripts represent significant differences (at 10% level or better) across the regions.

On average, about 52 percent of farmers in the three regions depend on non-farm income, which includes household income from formal salary and other business activities. Farms from South East district have significantly higher dependence on non-farm income. This could be due their proximity to the capital city, Gaborone, where most of the economic activities takes place.

However, this finding doesn't align with level of education which is an enabling factor for high-earning jobs in the civil service and other formal employment. Formal education is significantly higher for the Central and Chobe districts (Table 1). Similarly, the additional income derived from crop and small stock farming in both districts (Central; 59 percent; and Chobe; 56 percent) is significantly higher than those in South East. This is supported by the fact that crop land area owned by farms in Central and Chobe district is significantly higher.

As outlined by Bahta and Malope (2014), some land boards (land allocating authorities in tribal/communal land), do not allow crop production activities to take place in areas designated for livestock grazing. This has cost and productivity implications for livestock farmers, which are expected to be revealed in the current analysis which takes account of regional differences.

Households' average distance from the commonly-used market is 51.1 kilometers, but farmers in South East district report somewhat shorter distances to markets: as far away as about 35.64 kilometers. This implies that distance to an attractive market is a constraint to beef farms in Central and Chobe districts.

Table 1 further show beef farming is dominated by male and relatively old farmers. More than 75 percent of farmers in all the regions are male, although Central district farmers feature on average about a quarter female operators. There is only slight difference in the average age in all regions, but generally farmers in both South East and Chobe districts are slightly more aged. When it comes to farm experience, there is significant differences among the three regions with farmers in Chobe, followed by Central district, are more experienced in livestock farming.

Across the three regions, membership in agricultural group averages 16 percent and it is significantly higher for farmers in Chobe district. When asked about access to market information in the past year, more than 60 percent of the respondents in all farms indicated that they had such access and on average about 80 percent of all the beef farm households reported having access to veterinary advisory services. This result contradicts MFDP (2009), which reports that veterinary extension officers at the district extension offices are preoccupied with services other than assisting farmers. This result suggests the need for further investigation of veterinary services and the quality of the services farmers get from such institutions.

Results further indicate that only about 12 percent of households use controlled cattle breeding method which, in turn, further questions the quality of the services extension services provide. This finding is significantly low among farmers in South East and Chobe districts.

On average, 10 percent of all farmers have sold more than 50 percent of sold cattle to the Botswana Meat Commission (BMC)[6] in the period under study (2012/2013). The higher share comes from farmers

[6] Botswana Meat Commission (BMC), a government parastatal enterprise that has monopsony rights over the purchase of cattle for export and the sale of exported beef.

in Central district where about 20 percent of the farmers sold more than 50 percent of their cattle to BMC. Normally, BMC do not use contract sales, however, farmers who managed to sell to BMC can benefit from its services. The Botswana Meat Commission (BMC) is the principal market channel for the country's finished cattle and weaners (Bahta et al, 2013).

4. Result and discussion

Table 2 shows that for technical efficiency relative to meta-frontier, cattle farms in South East, Central and Chobe districts have a mean TE of 0.194, 0.331 and 0.318, respectively. The mean TE of Central and Chobe district Cattle farms is significantly higher than the South East cattle farms. The average pooled sample TE with respect to meta-frontier is 0.275. This indicates first, that there is considerable scope for improving smallholder beef production in Botswana.

Secondly, the stark difference between the regions, particularly the low record of TE in South East, point to where efficiency is at its lowest and this motivates targeted response. The mean meta-technology ratio (MTR) in the whole sample is 0.59; with about 96 percent of farmers across the three regions having MTR estimates below 1. This implies that, on average, beef farmers in Botswana produce 76 percent of the maximum potential output achievable from the available technology.

Moreover most of farmers, about 96 percent, have MTR estimates below 1, which indicate that they use the available technology, such as their use of cross breeds, sub-optimally. This could be due to low rates of adoption or poor utilization of adopted technologies influenced by, as described above, the quality of extension services they receive.

The average MTR is high in beef farmers who are located in Chobe district (Table 2). This is somehow consistent with the differences in relative levels of investments in the cattle enterprise by farmers in the three regions (indicated in Appendix 2). It is interesting to note that in all but cattle farms in South East, the value of the maximum meta-technology gap ratio obtained is 1 (Max MTR=1) which indicates that their group frontiers are tangent to the meta-frontier (Battese et al., 2004).

Table 2: Technical efficiencies and Meta technologies of different beef farm types

Model	South East (N=219)	Central (N=200)	Chobe (N=149)	Pooled sample (N=568)
TE w.r.t. the meta-frontier				
Mean	0.194[b]	0.331[a]	0.318[a]	0.275
Min	0.023	0.078	0.017	0.017
Max	0.351	0.704	0.676	0.704
SD	0.078	0.133	0.164	0.140
Meta-technology ratio				
Mean	0.387[c]	0.683[b]	0.743[a]	0.585
Min	0.281	0.439	0.484	0.281
Max	0.494	1.000	1.000	1.000
SD	0.043	0.161	0.128	0.198

Note: [a,b,c] differences in the superscripts represent significant differences (at 10% level or better) across the regions.

Therefore, more access to better technology (e.g. cattle breeds or feed planning techniques) is necessary in order those farmers who use technology sub-optimally achieve further productivity gains. The study showed that 96 percent of farmers use the available technology (e.g., cross breed cattle) sub-optimally. Perhaps this could be due to, as noted by Diagne (2010), lack of awareness of the technologies and/or how to use them that lead to low rates of adoption or poor use of agricultural technologies in sub-Saharan Africa. Consistent with relative levels of investments in the three regions and access to crop lands and other agricultural incomes (Appendix 2), the average MTR is higher in farms located in Chobe (0.68) and Central (0.74) districts. Bahta and Malope (2014) found that beef farms who have access to crop land and crop income are more efficient than those who doesn't have such access. They further highlighted the tendency amongst Botswana's farmers, who engage in other businesses and earn higher income from non-farm activities, in using livestock farming as a supplemental activity.

As noted above, the main objective of this study is to identify and explain sources of inefficiency, which are widely referred to as inefficiency effects (Coelli et al., 2005). To investigate possible determinants of inefficiency, the study used several socio-economic, technology related explanatory and regional variables. A test of multicollinearity using variance inflation factors (VIF)[7] was conducted to select or drop explanatory variables for the inefficiency model. Subsequently, a pooled meta-frontier was estimated using all the descriptive variables as possible determinants of inefficiency. Table 3 show that the results of the pooled meta-frontier estimation. The meta-frontier results show that an increase in the use of any of the four inputs used in the model would lead to significant improvement in output, assuming that beef farmers are rational decision makers.

Table 3 further shows that, the result of the test that there is no technical inefficiency component in the model. This is a test of the null hypothesis H0: σ_{u}^2=0 against the alternative hypotheses H1 : σ_{u}^2>0. If the null hypothesis is true, the stochastic frontier model reduces to an OLS model with normal errors. However, because the LR-test (Table 3) lies above on the boundary of the parameter space of σ_u^2, implying the presence of technical inefficiency in beef farming in Botswana. The estimated inefficiency effects from the model show that herd size, sales to BMC, controlled breeding method, other agricultural income and farm experience significantly increase efficiency while having more than 50 percent of indigenous breeds and interaction between income and education would reduce inefficiency. The result also shows the significant differential impact among the regions.

The observed significant statistical differences amongst the beef farms in three regions of Botswana suggests, as indicated in Battese et al. (2004), that the meta-frontier is appropriate for policy application. Therefore, subsequent discussion focuses on the results of the meta-frontier-Tobit model.

The coefficient on herd size is positive and statistically significant. This implies that farmers who own larger cattle herds are more efficient, possibly due to economies of scale. This finding is supported by Bahta and Malope (2014) who found that farmers with large cattle herds are more efficient in terms of profit. However, that study also acknowledges that the relationship between herd size and gross margin in Botswana is a complex one, and possibly governed by differences in technology and associated management systems and labor configuration (Bahta et al., 2013; BIDPA, 2006).

Table 3: Production function estimates and determinants of technical efficiency

Variable	Meta-frontier-Tobit	
	Coefficient	Standard error
Constant (β0)	8.46***	0.0001
Improved feed equivalents (β1)	0.03***	0.0001

[7] Prior test of multicollinearity in STATA 11 was conducted to select variables for the inefficiency model. As a rule of thumb, a variable whose VIF values are greater than 10 may merit further investigation. Tolerance, defined as 1/VIF, is used by many researchers to check on the degree of collinearity (Chen et al, 2003).

Veterinary cost (β2)	0.06***	0.0001
Labor (β3)	0.06***	0.0002
Divisia index for other costs (β4)	0.10***	0.0089
Inefficiency effects		
Constant (β0)	0.18***	0.0168
Beef herd size (δ1)	0.002***	0.0001
Indigenous breed (δ2)	-0.04***	0.0097
Non-farm income (δ3)	0.0009	0.0010
Age of farmer (δ4)	0.007	0.022
Gender (% female farmers)(δ5)	0.0012	0.0090
Sales to BMC (δ6)	0.03**	0.0137
Controlled breeding method (δ7)	0.05***	0.0129
Distance to commonly used market (Kms)(δ8)	0.0288	0.0797
Other agricultural income (% of farmers)(δ9)	0.091***	0.019
Farm experience	0.066***	0.022
Income-education (δ11)	-0.052*	0.031
Region (δ12)		
Central	0.07***	0.009
Chobe	0.10***	0.010
LR-test	7.79 (p-vale =0.003)	
N	568.00	
log likelihood function	584.30	

Notes: statistical significance levels: ***1%; **5%; *10%. Corresponding standard errors are shown in parentheses. The log likelihood of a Tobit model with continuous dependent variable (censored between 0 and 1, in this case) can be positive or negative because it represents the log likelihood of a density or cumulative density function, unlike in discrete distributions where the log likelihood is of a probability and always negative or zero (Greene, 1990).

The coefficient of indigenous breed is negative and statistically significant which implies, apart from the herd size, the importance of the genetic composition of cattle herd. That is, having less indigenous animals would increase efficiency.

This is further supported by the significance of the use of controlled breeding technology (Table 3) which is consistent with the view of Wollny (2003) that controlled cattle breeding might be expected to increase efficiency by improving genetic quality, enhancing adaptation of cattle to environmental conditions and ensuring a better fit of stocking rate to feed supply and markets within and between years. The results show that selling more cattle to BMC increases efficiency. Although there is no formal contract for selling cattle to BMC, farmers who are able to meet requirements and access BMC markets can benefit from BMC's year-round demand and on farm collection services.

However, Bahta et al, (2013) report that some farmers are reluctant to sell to BMC due to their lack of understanding on the quality requirement and inclined choice towards selling old animals. Normally BMC offers on farm collection service through its BMC agents to farmers who sales young animals or weaners. This is in line with the opinion of MacDonald et al. (2004) that sales contracts are important in enabling farmers to obtain steady and increased income through an assured market, and reduced input and output price risks. Therefore, based on BMC's above-mentioned continuous demand and service delivery, it is expected that farmers who meet the requirements and are able to sell more cattle to BMC, to be relatively more efficient. Here, it should be emphasized that the current finding should be interpreted within the current Botswana cattle trade regime since a study by Hamza, et al (2014) found that farmers benefit more if the current export monopoly of BMC is abolished.

The significance of experience suggests that, as noted by several authors (Lapar, et al. 2005; Mathijs and Vranken, 2001) there might be efficient use of inputs by farmers that emanates from application of their knowledge accumulated from experience. Three income variables were included in the meta-frontier-Tobit model to see their effect on TE. The significance of income from other agricultural activities implies that, as noted by Bahta and Malope (2014), there might be a considerable re-investment of such earnings in several farm activities by beef farmers in Botswana due to the synergies between cattle, small stock and crop activities. However, this is not the case for non- farm earnings which is not significant in the model. This could be due to, as noted by Rakipova et al. (2003), the time spent doing off-farm work reducing the time spent on efficiency-improving managerial activities. In fact there is a tendency amongst Botswana's farmers who engage in other businesses and higher earning non-farm activities, to use livestock farming as a supplemental activity. This may include the many so-called absentee[8] farmers in Botswana who are relatively educated (see Table 1) as the interaction between income and education[9] shows a negative impact on technical efficiency.

5. Conclusions

With the main objective of estimating efficiency levels and technology gaps across different technologies used by beef farms in three regions of Botswana and identifying the determinants of technical efficiency of beef farms, a meta-frontier-Tobit production function model, using cross-sectional survey data, is applied to beef-producing households in Botswana.

Results show that the majority of farmers use available technology sub-optimally and produces less than the potential beef output.

The average MTR (Meta Technology Ratio) and TE (Technical Efficiency), estimated for the whole sample, are 58.5 and 27.5, respectively. Further it was found that herd size, farmers' experience, cattle sales to BMC, controlled cattle breeding method and having additional agricultural income all contribute positively to efficiency. Conversely, having more indigenous cattle and income and formal education did not have a favorable impact on efficiency. These findings have important implications on policies directed towards improving beef production in Botswana: in part because indicators of households' strength and weakness are identified and in part because shortcomings of implementation or delivery of services (rather than their absence) are identified as problematic.

Consistent with *a priori* expectations, the results pointed out the importance of providing livestock farmers with relevant livestock extension and other support services that would facilitate better use of available technology by the majority of farmers who currently produce sub-optimally. Possible essential interventions would include improving farmers' access to appropriate knowledge on animal husbandry such as cattle feeding methods, disease monitoring and breeding. In addition, acquainting farmers to relatively better and affordable technology, such as locally adaptable breeds and breeding programs, would enable relatively efficient farmers to achieve further productivity gains. A key contribution of this study is however to signal the key roles played by different technologies in the different regions, and this

[8] Absentee farmers are farmers who engage in livestock farming on part time basis while engaging full time on other businesses or public services.

[9] Inclusion of formal education did not individually improve the model fit. By including the interaction between formal education and income the meta-frontier-Tobit model offers an improvement in the ability to explain TE.

indicates both the need for further research and for the identification and promotion of technologies which suit certain production and marketing models.

Beef farmers should be encouraged to undertake arable farming, especially fodder production, and keep small stock so as to improve their resilience to droughts and increase livelihood opportunities. This could be facilitated by allowing farmers to own arable lands near their vicinity of their livestock farms and organizing small stock markets, which at present are almost nonexistent. The current study has identified the variety of relationships which may exist between access to arable land and the location of farms.

Further, farmers should be provided with reliable market information, which could possibly help farmers make informed decisions before they travel to distant markets in search of better prices (Bahta and Malope, 2014). This helps farmers to understand the market quality requirements and benefit from the on farm collection services that the BMC offers through its agents.

6. Acknowledgements

This study was conducted as part of the Competitive Smallholder Livestock in Botswana project, funded by the Australian Centre for International Agricultural Research (ACIAR) and implemented by the International Livestock Research Institute and the Botswana Ministry of Agriculture's Department of Agricultural Research. The assistance and collaboration of local district authorities, and extension agencies in the South East, Central and Chobe districts of Botswana is gratefully acknowledged, as is the co-operation of farm households selected for the survey.

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Appendix 1

Note:

Due to measurement difficulties, this study follows the revenue approach recently applied in the literature (Hadley, 2006; Abdulai and Tietje, 2007; Gaspar *et al*., 2009) and defines output as:

$$Q_{i(j)} = \frac{\sum_r^R yP}{t} \tag{1}$$

where $Q_{i(j)}$ is the annual value of beef cattle output of the ith farm in the j^{th} region (measured in Botswana Pula[10]); r denotes any of the three forms of cattle output considered, i.e., current stock, sales or uses for other purposes in the past twelve-month period; y is the number of beef cattle equivalents[11]; p is the current price of existing stock or average price for cattle sold/used during the past twelve months; and t is the average maturity period for beef cattle in Botswana, which based on expert consultation is assumed to be four years.

Similarly, to ensure that the study captures the approximate share of feeds from different sources in each beef region, the quantities of purchased and non-purchased (on-farm) feeds were first adjusted in accordance with the average annual number of dry and wet months[12], respectively, in the country.

Average feed prices were computed using the survey's price information collected for purchased feed with further validation by animal nutrition experts in the Department of Agricultural Research (DAR). Both purchased and non-purchased feeds were then converted to improved feed equivalents by multiplying the respective feed quantities by the ratio of their prices (or shadow prices) to the average per unit price of improved fodder.

Thus, following Otieno (2011), the total annual improved feed equivalent was computed as:

$$\{\varphi(p_f * d) + S(n_p * w)\} \qquad (2)$$

Where; φ and S denote, respectively, the ratio of prices of purchased and non-purchased feed to that of improved fodder; p_f and n_p represent the average quantities of purchased and non-purchased feeds, respectively, in kilograms per month; d is the approximate number of dry months (when purchased feeds are mainly used), while w is the length of the wet season (when farmers mostly use on-farm or non-purchased feeds) in a particular area.

Depreciation costs on fixed inputs were based on the straight line method, using useful economic life farm equipment provided by each farm household. Labor costs comprise both paid and unpaid labor; the latter valued using the average minimum farm wage in a particular district. The labor costs were adjusted with the share of cattle income in household income. Similar adjustments were applied to other incidental variable costs, such as fuel and electricity bills.

To ensure consistent estimates of inefficiency effects in the SFA, a one-stage model is used, as proposed by Battese and Coelli (1995). In estimating the SFA both Cobb-Douglas and Translog production models were tested to test the model's fit to the survey data.

A likelihood ratio test showed that the Cobb-Douglas functional form provided a better fit to the survey data than a translog model[13.]

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[10] One Botswana Pula is on average 0.1261 USD (Yahoo Finance (2013).

[11] Following (Otieno, 2012; Hayami and Ruttan., 1970; O'Donnell et al., 2008). Beef cattle equivalents were computed by multiplying the number of cattle of various types by conversion factors. Following insights from discussions with BMC (Botswana Meat Commission), the conversion factors were calculated as the ratio of average slaughter weight of different cattle types to the average slaughter weight of a mature beef bull. The average slaughter weight of mature bull, considered to be suitable for beef in Botswana, is between 452-500kg. according to BMC, the average slaughter weights for castrated adult males (oxen>3 years), Immature males (< 3 years), Cows (calved at least once), Heifers(female ≥1yr,have not calved), Male calves (between 8 weeks&<1year),Female calves (between 8 weeks&<1year), , Pre weaning males (<8 weeks), Pre weaning females (<8 weeks) are 400kg, 350kg, 390kg,300kg,250kg, 220kg,95kg and 95 kg, respectively. The calculated average slaughter conversion factors were then: 1.0, 0.86, 0.76, 0.84, 0.65, 0.48, 0.54,0.21 and 0.21, for Bulls, castrated adult males, Immature males , Cows, heifers, Male calves, Female calves, Pre weaning males and Pre weaning females, respectively

[12] Botswana is an arid country and according experts information the length of the wet season when farmers mostly use on-farm or non-purchased feeds do not exceed 5 months. Consequently, the study uses 5 wet and 7 dry months, respectively.

[13] Following Battese et al (2004), the likelihood ratio (LR) statistic calculated as : -2{ln[L(Ho)]- ln[L(H1)]} where ln[L(Ho) and ln[L(H1)] are values of the log likelihood function for the Cobb-Douglas and translog models, respectively. The test fails to reject the null hypothesis that Cobb-Douglas model is a better specification of sample data, with a LR statistic of 59.12 compared to the chi-square critical value of 11.38 at 10% and 7 degrees of freedom. Degrees of freedom equal the difference in the number of parameters estimated in the two models.

All the parameters in the proposed stochastic frontier and technical inefficiency effects model were estimated simultaneously in the equation:

$$lnQ_{i(j)} = \beta_{0(j)} + \sum_{r=1}^{4} \beta_{r(j)} lnX_{ir(j)} - M_i\delta_j + v_{i(j)} \quad (3)$$

Where $Q_{i(j)}$ is the annual value of beef cattle output of the i[th] farm in the j[th] region and measured as indicated in (16). X_{ir} represents a vector of inputs where X_{i1} is total feed equivalents, X_{i2} denotes the cost of veterinary services, and X_{i3} is the cost labor, while X_{i4} is a Divisia index calculated as (Boshrabadi et al., 2008)[14]:

$$X_{i4} = \Pi_{r=1}^{2} C_{ir(j)}^{\propto ir} \quad (4)$$

Where $\alpha_{ir(j)}$ represents the share of the n[th] input in the total cost for the i[th] farm in the j[th] region; $C_{i1(j)}$ is the depreciation; insurance and taxes on farm buildings, machinery and equipment (Pula); $C_{i2(j)}$ represents other overhead costs including fuel, electricity, market services, maintenance costs, branding etc., in Pula terms.

M denotes the vector of socio-demographic and other independent variables assumed to influence efficiency; *v* represents statistical noise and δ is a vector of inefficiency parameters to be estimated.

Intuitively, a positive sign of the coefficient of efficiency driver variable (δ) implies inefficiency because the value of u (u=Mδ) would be higher when the farm is farther away below the frontier. On the contrary, a negative sign of the coefficient is interpreted as potentially having a positive influence on efficiency (Brummer and Loy, 2000; Coelli et al., 2005; Delgadoet al. 2008; Otieno et al. 2012).

The parameters of the stochastic frontiers were obtained by using FRONTIER 4.1 software (Coelli, 1996). The linear programming, to estimate meta-frontier (Equation 8), and bootstrapping of standard errors were undertaken in SHAZAM version 10 (Whistler *et al*., 2007), while STATA version 11 (StataCorp, 2009) was used for the Tobit analysis (Equation 13).

Appendixe 2

Average annual output and inputs

Variables	South East (N=219)	Central (N=200)	Chobe (N=149)	Pooled sample (N=568)
Value of beef cattle output (Pula)	17614[c]	47366[a]	28893[b]	31,048
Veterinary costs (Pula)	449[b]	619[a]	505[a]	524
Paid labor costs (Pula)	8693[a]	6862[c]	7951[b]	7854
Purchased feed equivalents (Kg)	399[a]	404[a]	277[b]	370
On-farm feed equivalents (Kg)	377[b]	815[a]	228[c]	492
Depreciation costs (Pula)	2591[b]	5331[a]	4923[a]	4168
Cost of other inputs (Pula)	2189[b]	5715[a]	4866[a]	4134

Notes: [a,b,c] differences in the superscripts represent significant differences (at 10% level or better) across the regions. Total labor costs and feed equivalents comprise both paid and unpaid labor, and purchased and on-farm feeds, respectively.

[14] The Divisia index is a proxy variable used to consolidate inputs such as depreciation and other costs so that to improve the model fit. All input costs are adjusted with the share of cattle income in household income.